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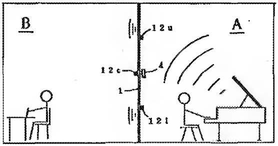
(54)【発明の名称】　アクティブ遮音方法

(57)【要約】

【目的】　重量壁やハニカム構造壁などを用いることなく、騒音源室と受音室とを仕切る壁の遮音性を高める。

【構成】　騒音源室Ａと受音室Ｂとを仕切る壁１の振動モードを解析して音の放射に関与する振動モードを特定し、その振動モードにおける壁１の低次元化モデルを作成し、得られた低次元化モデルの各質点に対応する壁１の各点に振動加速度乃至変位を検出するためのセンサ１２ｃ，１２ｕ，１２ｌを配置すると共に壁１の少なくとも１箇所に壁１に制振力を作用させるためのアクチュエータ４を取り付け、各センサ１２ｃ，１２ｕ，１２ｌからの検出信号に基づいて壁１の振動を抑制すべくアクチュエータ４を駆動する。音の放射に関与しない振動モードの振動を励起することなく、音の放射に関与する振動のみを対象としてこれを打ち消すように壁の振動を制御することができる。



1　壁
4　アクチュエータ
12c　センサ
12u　センサ
12l　センサ

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【特許請求の範囲】

【請求項1】　騒音源を内蔵する騒音源室と騒音低減を希望する受音室とを仕切る壁の振動モードを解析して音の放射に関与する振動モードを特定し、その振動モードにおける壁の低次元化モデルを作成し、得られた低次元化モデルの各質点に対応する壁の各点に振動加速度乃至変位を検出するためのセンサを配置すると共に壁の少なくとも1箇所に壁に制振力を作用させるためのアクチュエータを取り付け、各センサからの検出信号に基づいて壁の振動を抑制すべくアクチュエータを駆動するようにしたことを特徴とするアクティブ遮音方法。

【請求項2】　上記音の放射に関与する振動モードとして、その振動モード形が音響的に非対象であるモードを特定するようにした請求項1記載のアクティブ遮音方法。

【請求項3】　上記壁の上記低次元化モデルの質点に対応する箇所に上記アクチュエータを取り付けるようにした請求項1または2記載のアクティブ遮音方法。

【発明の詳細な説明】

【0001】

【産業上の利用分野】本発明は、騒音源室と受音室とを仕切る壁の振動特性を考慮し、壁の振動を制御することによって遮音性を高めるようにしたアクティブ遮音方法に関するものである。

【0002】

【従来の技術】騒音対策として、騒音源から発せられた音を空中で打ち消す方法と音の伝搬経路を途中で遮断する方法とが考えられる。前者については、騒音源からの音をマイクロホンで検出し、それと逆位相・同一振幅の信号をスピーカで生成して騒音検出点付近の音をキャンセル（相殺）するいわゆるアクティブキャンセラーによる騒音制御技術が出現し、ダクト、冷蔵庫、乗用車の社室内などの騒音低減に応用して成果をあげている。後者については、騒音源を内蔵する騒音源室と騒音低減を希望する受音室との間を音響透過損失の大きい壁で仕切ることにより騒音を遮蔽する受動的な方法が依然採用されている。

【0003】

【発明が解決しようとする課題】しかし、従来の遮音方法によって高い遮音性を得るためには、壁に鉛や鉄などの比重の大きい材料を用いるか、または、ハニカム構造などの分厚い吸音材等を用いる必要があり、現代のビルのように軽量化が要求され且つ容積的にも制限のある条件下においては適用が困難である。

【0004】本発明はこのような事情の下に創案されたものであり、その目的は、重量壁やハニカム構造壁などを用いることなく、高い遮音性を得ることのできるアクティブ遮音方法を提供することにある。

【0005】

【課題を解決するための手段】上記目的を達成するため

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に、本発明のアクティブ遮音方法においては、騒音源室と受音室とを仕切る壁の振動モードを解析して音の放射に関与する振動モードを特定し、その振動モードにおける壁の低次元化モデルを作成し、得られた低次元化モデルの各質点に対応する壁の各点に振動加速度乃至速度を検出するためのセンサを配置すると共に壁の少なくとも1箇所に壁に制振力を作用させるためのアクチュエータを取り付け、各センサからの検出信号に基づいて壁の振動を抑制すべくアクチュエータを駆動する。

【0006】本発明の遮音方法において、上記音の放射に関与する振動モードとして、その振動モード形が音響的に非対象であるモードを特定することが望ましい。

【0007】また、本発明の遮音方法において、上記壁の上記低次元化モデルの質点に対応する箇所に上記アクチュエータを取り付けることが望ましい。

【0008】

【作用】本発明のアクティブ遮音方法は、騒音源室と受音室とを仕切る壁が騒音と共振して振動することによって音漏れが発生するという点に着目し、音の放射に関与する振動のみを対象としてこれを打ち消すように壁の振動を制御しようとするものである。振動制御に有効な現代制御理論は制御対象のモデルが特定されなければ活用できないのであるが、壁は無限自由度の分布定数の特性を有するために、有限自由度のモデル作成する必要がある。しかも、自由度が大きいとコントローラが肥大化し、センサの数が多く必要であるために、必要最小限にモデルを低次元化することが望ましい。そのために、本発明の方法では、まず壁の振動モード解析を行い、遮音しようとする所定の周波数域内に数多く存在する振動モードの中から音の放射に関与する振動モードを特定し、その振動モードにおける壁の低次元化モデルを作成する。このように制御対象の低次元化モデルを作成することで、現代制御理論を適用して制御系を設計することが可能となる。そして、得られた低次元化モデルの各質点に対応する壁の各点すなわち特定された振動モードの最大振幅点付近に振動加速度乃至変位を検出するためのセンサを配置しておくことで、制御対象すなわち壁の振動状態を観測でき、各センサからの検出信号に基づいてアクチュエータを駆動することにより、壁の振動を効果的に抑制することができる。

【0009】図5は壁を構成する平板の振動モード解析例であり、1～5次の共振周波数と振動モード形が示されている。振動モード形の対称性に着目すると、2～4次の振動モード形は音響的に対称、1次と5次の振動モード形は音響的に非対称であり、音響的に対称のモードの場合音の吐き出しと吸い込みの量が互いにキャンセルすると仮定すると、音の放射に関与する問題となる振動モードは音響的に非対称のモードである1次と5次のモードである。このように振動モード形の対称性を調べることによって、音の放射に関与する振動モードを容易に

特定できる。

【0010】このようにして特定された振動モードの最大振幅点は、音の放射に関与しない他の振動モードの節にあたる。したがって、この点にアクチュエータを取り付けておけば、音の放射に関与しない振動モードの振動を励起することなく、音の放射に関与する振動のみを対象としてこれを打ち消すように壁の振動を制御することができる。すなわち、本発明のアクティブ遮音方法は、振動モードの節にアクチュエータを取り付ければ不可制御、センサを取り付ければ不可観測になることを利用して、無視したいモードの節にセンサ、またはアクチュエータを配置して壁の振動を制御するものであり、この方法によれば構造的にスピルオーバを防止できる制御系を構築できる。

【0011】

【実施例】次に、本発明のアクティブ遮音方法の実施例について説明する。

【0012】図1は騒音源室（ピアノ室）Aと受音室（勉強室）Bとを仕切る壁1に本発明のアクティブ遮音方法を適用した場合の一例が示されている。騒音源室Aの騒音は壁1を介して受音室Bに伝達されるのであるから、壁1に取り付けた振動センサ１２ｃ，１２ｕ，１２１からの信号に基づいてアクチュエータ４を駆動して壁１の振動を効果的に抑制すれば受音室Bの騒音レベルが大幅に低減する。

【0013】図2に、壁の振動を本発明の手法でアクティブに制御するためにとられる装置構成の２通りの形態を示す。同図（ａ）は、アクチュエータ４を固定面に支持させて壁１に取り付け、センサ１２ｃ，１２ｕ，１２１の検出信号に基づいてコントローラ１９で作られた制御量によってアクチュエータ４を制御して壁１に制振力を作用させる方式であり、同図（ｂ）は、アクチュエータ４を弾性体（ここでは支持ばね２０でモデル化）を介して壁１に取り付け、固定面の代りにアクチュエータ４に設けた補助質量ｍｄの慣性力を反力としてアクチュエータ４の制振力を壁１に作用させる方式である。なお、同図（ａ）において、固定面が得られない場合は別途支持部材によってアクチュエータ４を支える。その場合、支持構造物の特性を考慮してコントローラ１９を設計することが望ましい。

【0014】次に、本発明のアクティブ遮音方法の有効性を示すために、建築物の壁を構成する平板にこの方法を適用した場合についてシミュレーションおよび実験により示す。

【0015】実験に使用した平板は、1200×1000×3 ㎜のベニヤ板である。図3に示すように、この平板１８を垂直壁２に固定された支持枠３に周辺部を固定して取り付けることにより地面に対して垂直に保持した。そして、図4に示すように平板１８を120 個の有限要素に分解し、実験モード解析を行った。この解析結果からこの平板には 0Hz〜40Hzの間に１次から７次の振動モードが存在することがわかった。図5は、この場合の１次〜５次の共振周波数と振動モード形を示したものであり、前述したように、音響的に対称の振動モードの場合音の吐き出しと吸い込みの量が互いにキャンセルすると仮定すると、ここで問題となる振動モードは１次と５次のモードである。

【0016】次に、上記考察の下に、実験モード解析により求まった分布定数系の平板１８の振動モード形に基づき、図4に示した平板１８上の位置に3つの質点を指定して図4のような３質点系モデルを作成する。ここに各質点の質量を m_1 ，m_2 ，m_3 、各質点をつなぐばねのばね定数を k_{ij}（ｉ，ｊは各質点の番号）、各質点と固定面間のばねのばね定数を k_i （ｉ＝１，２，３）と定義する。ただし、各質点には、各々制御力を含む外力 f_i （ｉ＝１，２，３）が作用するものとする。この3質点系モデルの運動方程式をたてると次のようになる。

【0017】

【数１】

$$m_1X_1+(k_1+k_{12}+k_{13})x_1-k_{12}x_2-k_{13}x_3=f_1 \qquad (1)$$

$$m_2X_2+(k_{12}+k_2+k_{23})x_2-k_{12}x_1-k_{23}x_3=f_2 \qquad (2)$$

$$m_3X_3+(k_{13}+k_{23}+k_3)x_3-k_{23}x_2-k_{13}x_1=f_3 \qquad (3)$$

【0018】この式を行列表示すると、

【0019】

【数２】

$$\begin{bmatrix} m_1 & 0 & 0 \\ 0 & m_2 & 0 \\ 0 & 0 & m_3 \end{bmatrix}\begin{Bmatrix} x_1 \\ x_2 \\ x_3 \end{Bmatrix} + \begin{bmatrix} k_1+k_{12}+k_{13} & -k_{12} & -k_{13} \\ -k_{12} & k_{12}+k_2+k_{23} & -k_{23} \\ -k_{13} & -k_{23} & k_{13}+k_{23}+k_3 \end{bmatrix}\begin{Bmatrix} x_1 \\ x_2 \\ x_3 \end{Bmatrix} = \begin{Bmatrix} f_1 \\ f_2 \\ f_3 \end{Bmatrix} \qquad (4)$$

【0020】となる。そこでこの式の固有値問題を解いて得られた固有モード行列を以下のようにおく。

【0021】

【数３】

$$\Phi = \begin{bmatrix} \phi_{11} & \phi_{12} & \phi_{13} \\ \phi_{21} & \phi_{22} & \phi_{23} \\ \phi_{31} & \phi_{32} & \phi_{33} \end{bmatrix} \qquad (5)$$

ただし ϕij:（iは質点番号，jはモード次数）

【0022】一方、物理座標系の質量行列Mの逆行列と固有モード行列との関係は、

【0023】

【数４】

$$M^{-1}=\Phi\Phi^T=\begin{bmatrix}\phi_{11}^2+\phi_{22}^2+\phi_{33}^2 & A & B \\ A & \phi_{21}^2+\phi_{22}^2+\phi_{23}^2 & C \\ B & C & \phi_{31}^2+\phi_{32}^2+\phi_{33}^2\end{bmatrix} \quad (6)$$

ここに，

$A=\phi_{11}\phi_{21}+\phi_{12}\phi_{22}+\phi_{13}\phi_{23}$，$B=\phi_{11}\phi_{31}+\phi_{12}\phi_{32}+\phi_{13}\phi_{33}$

$C=\phi_{21}\phi_{31}+\phi_{22}\phi_{32}+\phi_{23}\phi_{33}$

モードの対称性により，

$\phi_{11}=\phi_{31}$，$\phi_{13}=\phi_{33}$，$\phi_{12}=-\phi_{32}$，$\phi_{22}=0$

【0024】加速度連成の無い質量行列の性質より、A，B，Cは零でなければならない。そこで誤差関数ε_1，ε_2を次のように定義し、これらを零に近付けることを考える。

【0025】

【数5】

$$A=C=\phi_{11}\phi_{21}+\phi_{13}\phi_{23}=\varepsilon_1,\quad B=\phi_{11}^2-\phi_{12}^2+\phi_{13}^2=\varepsilon_2$$

【0026】各式に含まれる5つの変数φ11，φ21，φ12，φ13，φ23の感度行列を式（7）のように定義し、さらに補正ベクトル｛δφ｝を定義すれば式（8）によって誤差関数を零に近付けることができる。

【0027】

【数6】

$$\begin{bmatrix}\dfrac{\partial\varepsilon_1}{\partial\phi} \\ \dfrac{\partial\varepsilon_2}{\partial\phi}\end{bmatrix}=\begin{bmatrix}\phi_{21} & \phi_{12} & 0 & \phi_{23} & \phi_{13} \\ 2\phi_{11} & 0 & -2\phi_{12} & 2\phi_{13} & 0\end{bmatrix} \quad (7)$$

$$\begin{bmatrix}\dfrac{\partial\varepsilon_1}{\partial\phi} \\ \dfrac{\partial\varepsilon_2}{\partial\phi}\end{bmatrix}\begin{Bmatrix}\delta\phi_{11} \\ \delta\phi_{21} \\ \delta\phi_{12} \\ \delta\phi_{13} \\ \delta\phi_{23}\end{Bmatrix}=-\begin{Bmatrix}\varepsilon_1 \\ \varepsilon_2\end{Bmatrix} \quad (8)$$

【0028】式（8）によって式（6）を対角化する固有モード行列を求め、質量行列を計算すると次のように求まる。

【0029】

【数7】

$$\begin{bmatrix}m_1 & 0 & 0 \\ 0 & m_2 & 0 \\ 0 & 0 & m_3\end{bmatrix}=\begin{bmatrix}0.3075 & 0 & 0 \\ 0 & 0.5876 & 0 \\ 0 & 0 & 0.3075\end{bmatrix} \quad (9)$$

【0030】さらに、剛性行列を計算すると次のように求まる。

【0031】

【数8】

$$\begin{bmatrix}k_1+k_{12}+k_{13} & -k_{12} & -k_{13} \\ -k_{12} & k_{12}+k_2+k_{23} & -k_{23} \\ -k_{13} & -k_{23} & k_{13}+k_{23}+k_3\end{bmatrix}$$
$$=\begin{bmatrix}0.69\times10^4 & -0.72\times10^4 & 0.30\times10^4 \\ -0.72\times10^4 & 1.22\times10^4 & -0.72\times10^4 \\ 0.30\times10^4 & -0.72\times10^4 & 0.69\times10^4\end{bmatrix} \quad (10)$$

【0032】これらの式から、図4に示した集中定数系3自由度モデルの物理定数は次のように求まる。

【0033】

【数9】

$m_1=0.3075$[kg]，$m_2=0.5876$[kg]，$m_3=03075$[kg]

$k_1=0.28\times10^4$[N/m]，$k_2=-0.21\times10^4$[N/m]

$k_3=0.28\times10^4$[N/m]，$k_{12}=0.72\times10^4$[N/m]

$k_{23}=0.72\times10^4$[N/m]，$k_{13}=-0.30\times10^4$[N/m]

【0034】実際の実験モード解析で得られた振動モード形と本モデル化法で得られた振動モード形との比較を図7に示す。同図において、細い実線が実験モード解析により求められたモード形、太い実線が本モデル化手法で得られたモード形であり、3つの質点でモードが一致していることがわかる。

【0035】上記のように作成された低次元化モデルに対し、各モードの中でも振幅が最大の1次の振動モードを制御することを重視し、中央の質点（質量m_2）にアクチュエータを取り付けた場合における制御系の設計を行う。この中央の点は、2次、3次、4次の振動モードの節にあたるので、これらのモードの振動を励起しない点である。また、この点は実際の平板18の中央の点に相当する。

【0036】この発明のアクティブ遮音方法において使用されるアクチュエータ4は、スピーカの改良品であり、図9に示すように可動芯管5の周囲に巻き付けられたムービングコイル6と、これを包囲するリング状磁石7とを備え、ムービングコイル6への通電を制御することによりこれに電磁力を作用させて可動芯管3に取り付けられた振動板8を駆動する仕組みになっている。アクチュエータ4は、図1に示すように平板18の支持枠2に互いに平行に掛け渡して設けられた一対の支持部材9にリング状磁石7のフランジ部7aをボルト10で固定することによって平板18の中央位置に保持され、平板18との接続は、振動板8の中央部に突設された先細の接続子11の先端部を平板18の中央の点に接着などの方法によって接続することによりなされる。なお、図9において、リング状磁石7を含む固定側要素に対する振動板8を含む可動側要素の支持部は、ばね（ばね定数k_s）と減衰要素（減衰係数C_s）とでモデル化して示されている。

【0037】そこで、このアクチュエータ4を平板18に取り付けた場合の低次元化物理モデルは図8のように表わされる。なお、この物理モデルは、支持部材9を完全な剛体として考えており、図2（a）の場合のモデルに相当する。

【0038】この物理モデルを用いて質量m_2にアクチュエータ4を取り付けた場合の運動方程式を作成し、これを状態方程式で表すと以下のようになる。

【0039】

【数10】

$$\dot{X} = AX + bu \tag{17}$$

ここで，

$$X = [\dot{x}_1\ \dot{x}_2\ \dot{x}_3\ x_1\ x_2\ x_3] \tag{18}$$

$$A = \begin{bmatrix} 0 & 0 & 0 & -\frac{k_1+k_{12}+k_{13}}{m_1} & \frac{k_{12}}{m_1} & \frac{k_{13}}{m_1} \\ 0 & \frac{C_s}{m_2} & 0 & \frac{k_{12}}{m_2} & -\frac{k_{12}+k_2+k_{23}+k_s}{m_2} & \frac{k_{23}}{m_2} \\ 0 & 0 & 0 & \frac{k_{13}}{m_3} & \frac{k_{23}}{m_3} & -\frac{k_{13}+k_{23}+k_3}{m_3} \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix} \tag{19}$$

$$b = K_f\left[0\ \frac{1}{m_2}\ 0\ 0\ 0\ 0\ 0\right] \tag{20}$$

【0040】このように制御系が状態方程式で表されたならば現代制御理論である最適制御理論が適用できる。最適制御理論では、次のような状態フィードバックによって制御量を決定する。

【0041】

【数11】

$$u = -KX \tag{21}$$

$$K = [K_1\ K_2\ K_3\ K_4\ K_5\ K_6] \tag{22}$$

ここで，Kは以下の評価関数Jを最小とするゲインである．ここでQおよびRは重み行列である．．

$$J = \int_0^{\infty} (XQX^t + uRu^t)dt \tag{23}$$

【0042】以上の設計値を用いて平板18の振動制御のシミュレーションを行った。その周波数応答の結果を図10に示す。同図において、（a）は平板18の中央の点における周波数応答を示し、（b）は平板18の5次の振動モードの一方の腹に取り付けられるセンサの点での応答を示す。（a）に示すようにアクティブ制御を加えた場合には1次および5次のモードの振動のピークが低減しており、有効な遮音効果が期待できる。また（b）においてはアクチュエータ4の取り付け位置が平板18の中央であることから2次の振動モードに対しては不可制御になるが、本シミュレーションの結果から2次の振動モードのピークに影響を与えずに1次および5次の振動モードのピークを低減できることがわかる。

【0043】次に、図11にこの周波数応答に対応した時間応答を示す。平板18の中央の点での時間応答は、同図（a）に示すように、アクティブ振動制御により急速に収斂している。また、平板18の上部の点での時間応答は、同図（b）に示すように、周波数応答と同じく2次のピークが残留するが、1次、5次のモードは収斂している。

【0044】次に、図3に示すように、平板18の中央の点Pc及び5次の振動モードの2つの腹（上部および下部）の点Pu，Plに各点の変位を検出するための非接触センサ12c，12u，12lを配置し、アクチュエータ4を作動させた場合と非作動の場合のそれぞれの変位データを測定した。

【0045】この実験で使用したコントローラ19の構

成を図12に示す。この構成において、各非接触センサ12c，12u，12lからの変位信号はサンプリング周波数1kHzでA／Dコンバータ13を通してパーソナルコンピュータ14に入力される。パーソナルコンピュータ14は、この変位信号の微分により速度信号を算出し、各状態量を得る。そして得られた状態量に最適制御理論を用いて決定したフィードバックゲインを乗算することにより制御量を算出する。パーソナルコンピュータ14で算出された制御量はD／Aコンバータ15でアナログ信号に変換されたのちアンプ16で増幅されてアクチュエータ4に入力される。この入力信号によってアクチュエータ4が駆動して平板18の振動を抑制する。

【0046】図13に、平板18の上部をインパルス加振し、FFT解析器で得られた周波数応答を示す。同図において、点線が非制御時の応答、実線が制御時の応答である。また、（a）は平板18の中心部に取り付けたセンサ12cで検出された応答であり、（b）は平板18の上部に取り付けたセンサ12uの点での応答を示している。双方とも非制御時は1次、5次の周波数のピークが観測される。この平板18に制御をかけると、1次、5次のピーク値は大きく低下しており、振動が有効に制御されていることがわかる。また、図14（b）においては、アクチュエータ4を2次の振動モードの不可制御点である平板18の中央の点に設けたことにより、2次のモードの振動が励起されずに観測されている。これはシミュレーションの結果と非常に良く一致しており、これにより3質点系モデルの有効性がわかる。また、同時にさらに高次のモードである6次、7次のモードについてもスピルオーバーヲ発生させずに振動を抑制できることがこの実験結果からわかる。

【0047】したがって、上記制御系の構成を実際の建築物の騒音源室と受音室とを仕切る壁1に適用することにより、音の放射に関与する壁の振動を防止でき、重量壁やハニカム構造壁などを用いることなく高い遮音性を得ることができる。なお、実際の壁1にこの方法を適用する場合、図12に示したコントローラ19のパーソナルコンピュータ14をマイコンチップやメモリ素子など必要最小限度のものにおきかえることができる。

【0048】上記実施例において、アクチュエータ4を支持する支持部材9の振動を考慮して制御系を設計しておけば、より効果的に壁の振動を制御でき、上記の例よりもさらに高い遮音性を得ることが可能である。この制御系を設計するための物理モデルは、例えば図14のように作成される。この物理モデルは、図8に示したモデルにおいてアクチュエータ4のモデル要素と固定面との間に支持部材9のモデル要素、すなわち支持部材9の集中質量m_c並びにばね定数k_cを加えたものである。

【0049】この物理モデルを用いて運動方程式を作成し、これを状態方程式で表すと以下のようになる。ただし簡単のため、アクチュエータ4の減衰要素C_sは無視

する。

【0050】

＊【数12】

＊

$$
\begin{bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \\ \ddot{x}_3 \\ \ddot{x}_c \\ \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_c \end{bmatrix}
=
\begin{bmatrix}
0000 & -\frac{k_1+k_{12}+k_{13}}{m_1} & \frac{k_{12}}{m_1} & \frac{k_{13}}{m_1} & 0 \\
0000 & \frac{k_{12}}{m_2} & -\frac{k_2+k_{12}+k_{23}+k_5}{m_2} & \frac{k_{23}}{m_2} & \frac{k_5}{m_2} \\
0000 & \frac{k_{13}}{m_3} & \frac{k_{23}}{m_3} & -\frac{k_3+k_{23}+k_{13}}{m_3} & 0 \\
0000 & 0 & \frac{k_5}{m_c} & 0 & -\frac{k_c+k_5}{m_c} \\
1000 & 0 & 0 & 0 & 0 \\
0100 & 0 & 0 & 0 & 0 \\
0010 & 0 & 0 & 0 & 0 \\
0001 & 0 & 0 & 0 & 0
\end{bmatrix}
\begin{bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \\ \ddot{x}_3 \\ \ddot{x}_c \\ \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_c \end{bmatrix}
+
\begin{bmatrix} 0 \\ \frac{k_c}{m_2} \\ 0 \\ -\frac{k_c}{m_c} \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} u
\qquad (24)
$$

【0051】この状態方程式に最適制御理論を適用して制御量を決定することにより、アクチュエータ4の支持部材9をも含めた制御系を設計することができる。その場合の制御装置は、コンピュータ14に格納するプログラムやデータなどを変更することにより、図12と同じ構成のものが使用できる。

【0052】なお、本発明のアクティブ遮音方法は以上の実施例に限定されるものではなく、例えば、アクチュエータ4の取り付け箇所は、音の放射に関与する振動モードに制振力を作用させることができ、且つ音の放射に関与しない振動モードを励起しない箇所であれば平板18の中央部以外でもよく、また、平板18の複数の箇所に取り付けてもよい。アクチュエータ4を複数使用した場合、制御系は上記の例よりも複雑なものになるが、より遮音性の高い平板18の振動制御が可能である。

【0053】また、上記非接触センサ12c，12u，121に代えて加速度センサを使用してもよい。加速度センサは平板18に直接取り付けて使用できるので、支持フレーム3などの振動を平板18の振動として誤検出することがなく、実際の制御系には非接触センサよりも適している。

【0054】また、本発明のアクティブ遮音方法は、上記例で示したベニヤ板の他に、鉄板や硝子板、その他種々の壁材に適用でき、また、乗用車や船舶などの壁にも有効に適用できる。

【0055】また、騒音室の事例としてはこの実施例に示したピアノ室の他にも各種演奏室や機関室など種々な事例が考えられる。さらに、壁を船体の外壁と考えれば、音のパターンで認識される船の特徴を本発明のアクティブ遮音方法によって任意に変えることもできる。

【0056】

【発明の効果】以上要するに、本発明のアクティブ遮音方法によれば以下のごとき優れた効果を発揮できる。

【0057】(1)　請求項1記載の発明によれば、音※※の放射に関与する壁の振動モードを特定しこれを打ち消すように壁の振動を制御するので、重量壁やハニカム構造壁などの音響透過損失の大きい壁を使用することなく遮音性の向上を図ることができる。

【0058】(2)　請求項2記載の発明によれば、振動モード形の対称性を調べることによって、音の放射に関与する振動モードを容易に特定できる。

【0059】(3)　請求項3記載の発明によれば、音の放射に関与しない振動モードの振動を励起することなく、音の放射に関与する振動のみを対象としてこれを打ち消すように壁の振動を制御することができる。

【図面の簡単な説明】

【図1】本発明のアクティブ遮音方法の一実施例を示す概念図である。

【図2】本発明のアクティブ遮音を実施するための装置構成を示す概略図である。

【図3】本発明のアクティブ遮音方法の有効性を示すための実験装置の一例を示す図であり、(a)は正面図、(b)は(a)のA－A´断面図である。

【図4】壁を構成する平板の構造とその物理モデルの質量を示す概念図である。

【図5】実験モード解析によって得られた平板の振動モードを示す図である。

【図6】平板の物理モデル(低次元化モデル)を示す図である。

【図7】実験および計算によって得られた平板の振動モード形とその平板の低次元化モデルを示す図である。

【図8】アクチュエータを取り付けた場合の物理モデルを示す図である。

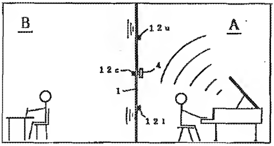
【図9】アクチュエータの構造を示す断面図である。

【図10】シミュレーションによる周波数応答の結果を示す図である。

【図11】図8の周波数応答に対応した時間応答を示す図である。

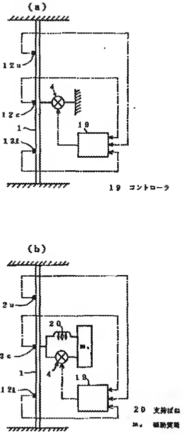
【図１２】実験に用いたコントローラの構成図である。
【図１３】シミュレーションによる周波数応答の結果を示す図である。
【図１４】アクチュエータを取り付けた場合の物理モデルの他の例を示す図である。
【符号の説明】
1　壁
4　アクチュエータ
12c　センサ
12u　センサ
121　センサ
A　騒音源室
B　受音室

【図1】

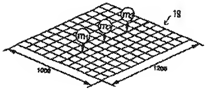


1　壁
4　アクチュエータ
12c　センサ
12u　センサ
121　センサ

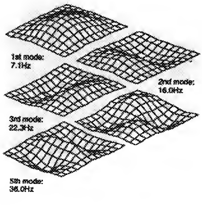
【図2】



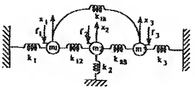
【図4】



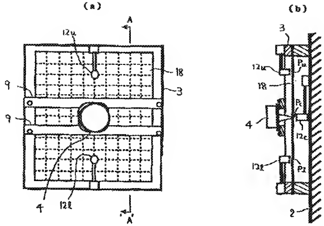
【図5】



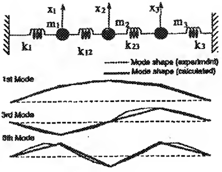
【図6】



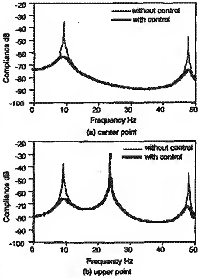
【図3】



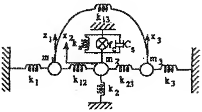
【図7】



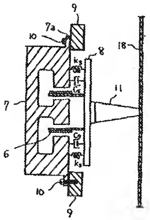
【図10】



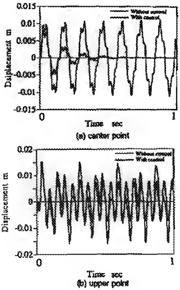
【図8】



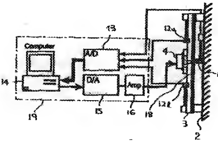
【図9】



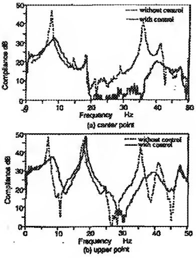
【図11】



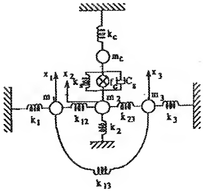
【図12】



【図13】


without control
with control
Compliance dB
Frequency Hz
(a) center point
without control
with control
Compliance dB
Frequency Hz
(b) upper point

【図14】


k_c
m_c
x_1
x_2
k_s
f_c
C_s
x_3
m_1
m_2
m_3
k_1
k_{12}
k_{23}
k_3
k_2
k_{13}

2/2 B

PATENT ABSTRACTS OF JAPAN

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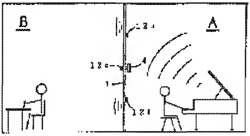
(54) ACTIVE NOISE INSULATING METHOD

(57)Abstract:

PURPOSE: To improve the noise insulation of a wall partitioning between a noise source room and a sound receiving room without using a weight wall or honeycomb structure wall.



CONSTITUTION: The vibration mode of the wall 1 partitioning between the noise source room A and the sound receiving room B is analyzed to specify a vibration mode relating to the radiation of sound, a low-dimensional model for the wall 1 in the vibration mode is prepared, sensors 12c, 12u, 12l for detecting the acceleration/displacement of vibration are arranged on respective points of the wall 1 which correspond to respective mass points of the obtained low-dimensional model, and an actuator for applying braking force to the wall 1 is fixed at least to one position of the wall 1 and driven so as to suppress the vibration of the wall 1 based upon detection signals outputted from the sensors 12c, 12u, 12l. Consequently the vibration of the wall 1 can be controlled so as to cancel only vibration relating to the radiation of sound without exciting the vibration of a vibration mode unrelated to the radiation of sound.

CLAIMS

[Claim(s)]
[Claim 1]The mode of vibration which analyzes the mode of vibration of a wall which divides a sound receiving room which wishes a noise source room which builds in a noise source, and a noise reduction, and participates in radiation of a sound is specified, Arrange a sensor for detecting the acceleration of vibration thru/or displacement on each point of a wall corresponding to each mass point of a low dimension-ized model obtained by creating a low dimension-ized model of a wall in the mode of vibration, and an actuator for making damping force act on a wall is attached to at least one place of a wall, An active noise insulation method characterized by making it drive an actuator that vibration of a wall should be controlled based on a detecting signal from each sensor.
[Claim 2]An active noise insulation method according to claim 1 which specified the mode in which the mode-of-vibration form was a non-object acoustically, as the mode of vibration which participates in radiation of the above-mentioned sound.
[Claim 3]An active noise insulation method according to claim 1 or 2 which attached the above-mentioned actuator to a part corresponding to a mass point of the above-mentioned low dimension-ized model of the above-mentioned wall.

[Translation done.]

DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[Industrial Application]This invention relates to the active noise insulation method which improved insulation by controlling vibration of a wall in consideration of the oscillation characteristic of the wall which divides a noise source room and a sound receiving room.
[0002]
[Description of the Prior Art]How to negate the sound emitted from the noise source as a measure against noise in the air, and the method of intercepting the propagation path of a sound on the way can be considered. The noise control art what is called by an active canceler which detects the sound from a noise source with a microphone, generates the signal of it, and an opposite phase and the same amplitude by a loudspeaker, and cancels the sound near a noise detecting point about the former (offset) appears, It applies to noise reductions, such as the shrine interior of a room of a duct, a refrigerator, and a passenger car, and the result is got. About the latter, the passive method of covering noise is still adopted by dividing with the large wall of sound transmission loss between the sound receiving rooms which wish the noise source room which builds in a noise source, and a noise reduction.
[0003]
[Problem(s) to be Solved by the Invention]However. [whether material with large specific gravity of lead, iron, etc. is used for a wall in order to acquire high insulation by the conventional noise insulation method, and] Or application is difficult under the condition where needs to use thick sound-absorbing materials, such as honeycomb structure, etc., and a weight saving is required like a present-day building and which has restriction also in capacity.
[0004]This invention is originated under such a situation, and the purpose is to provide the active noise insulation method that high insulation can be acquired, without using a weight wall, a honeycomb structure wall, etc.
[0005]
[Means for Solving the Problem]To achieve the above objects, in an active noise insulation method of

this invention, The mode of vibration which analyzes the mode of vibration of a wall which divides a noise source room and a sound receiving room, and participates in radiation of a sound is specified, Arrange a sensor for detecting the acceleration of vibration thru/or speed on each point of a wall corresponding to each mass point of a low dimension-ized model obtained by creating a low dimension-ized model of a wall in the mode of vibration, and an actuator for making damping force act on a wall is attached to at least one place of a wall, An actuator is driven that vibration of a wall should be controlled based on a detecting signal from each sensor.

[0006]In a noise insulation method of this invention, it is desirable to specify the mode in which the mode-of-vibration form is a non-object acoustically, as the mode of vibration which participates in radiation of the above-mentioned sound.

[0007]In a noise insulation method of this invention, it is desirable to attach the above-mentioned actuator to a part corresponding to a mass point of the above-mentioned low dimension-ized model of the above-mentioned wall.

[0008]

[Function]The active noise insulation method of this invention tends to control vibration of a wall to negate this only for vibration which participates in radiation of a sound paying attention to the point that the leakage of the sound occurs, when the wall which divides a noise source room and a sound receiving room resonates with noise and vibrates. since modern control theory effective in vibration control is unutilizable if the model of a controlled object is not specified, but a wall has the characteristic of the distribution constant of infinite flexibility -- model creation of limited flexibility -- it is necessary to carry out And if flexibility is large, a controller will be enlarged, and since many number of sensors is necessities, it is desirable to low-dimension-ize a model to necessary minimum. Therefore, in the method of this invention, the mode of vibration which participates in radiation of a sound out of the mode of vibration which conducts mode-of-vibration analysis of a wall first, and exist in the predetermined frequency area which is going to insulate is specified, and the low dimension-ized model of the wall in the mode of vibration is created. Thus, it becomes possible to design a control system with the application of modern control theory by creating the low dimension-ized model of a controlled object. By and the thing for which the sensor for each point of the wall corresponding to each mass point of the obtained low dimension-ized model, i.e., near the peak magnitude point of the mode of vibration which were pinpointed, detecting the acceleration of vibration thru/or displacement is arranged. The vibrational state of a controlled object, i.e., a wall, can be observed, and vibration of a wall can be effectively controlled by driving an actuator based on the detecting signal from each sensor.

[0009]Drawing 5 is a monotonous example of mode-of-vibration analysis which constitutes a wall, and the 1-5th resonance frequency and a mode-of-vibration form are shown. When its attention is paid to the symmetry of a mode-of-vibration form, acoustically the 2-4th mode-of-vibration forms Symmetry, When it assumes that the primary mode-of-vibration form [5th] is acoustically unsymmetrical, and the discharge of a sound and the quantity of a suction cancel it mutually acoustically in the case of the symmetrical mode, the mode of vibration which poses a problem which participates in radiation of

a sound is the primary mode [5th] that is the unsymmetrical mode acoustically. Thus, by investigating the symmetry of a mode-of-vibration form, the mode of vibration which participates in radiation of a sound can be specified easily.
[0010]Thus, the peak magnitude point of the specified mode of vibration is equivalent to the paragraph of other modes of vibration which do not participate in radiation of a sound. Therefore, vibration of a wall can be controlled to negate this only for vibration which participates in radiation of a sound, without exciting vibration of the mode of vibration which does not participate in radiation of a sound, if the actuator is attached to this point. That is, if an actuator is attached to the paragraph of the mode of vibration and improper control and a sensor will be attached, the active noise insulation method of this invention will arrange a sensor or an actuator in the paragraph in the mode in which he would like to ignore, using becoming improper observation, and will control vibration of a wall. According to this method, the control system which can prevent spillover structurally can be built.

[0011]
[Example]Next, the example of the active noise insulation method of this invention is described.
[0012]An example when drawing 1 applies the active noise insulation method of this invention to the wall 1 which divides the noise source room (piano room) A and the sound receiving room (study for children) B is shown. Since it is transmitted to the sound receiving room B via the wall 1, if the noise of the noise source room A drives the actuator 4 based on the signal from the vibration sensors 12c, 12u, and 12l. attached to the wall 1 and vibration of the wall 1 is controlled effectively, the noise level of the sound receiving room B will reduce it substantially.
[0013]Two kinds of gestalten of the equipment configuration taken in order to control vibration of a wall by the technique of this invention actively are shown in drawing 2. The figure (a) is a method which makes a fixing face support the actuator 4, attaches to the wall 1, controls the actuator 4 by the controlled variable made by the controller 19 based on the sensors [12c, 12u, and 12l.] detecting signal, and makes damping force act on the wall 1.
The figure (b) is a method which attaches the actuator 4 to the wall 1 via an elastic body (here, a model is made by the retaining spring 20), and makes the damping force of the actuator 4 act on the wall 1 by making into reaction force the inertia force of the auxiliary mass md provided in the actuator 4 instead of the fixing face.
In the figure (a), when a fixing face is not acquired, the actuator 4 is separately supported by a support member. In that case, it is desirable to design the controller 19 in consideration of the characteristic of a support structure.
[0014]Next, in order to show the validity of the active noise insulation method of this invention, a simulation and an experiment show the case which constitutes the wall of a building where this method is applied monotonously.
[0015]The plate used for the experiment is plywood of 1200x1000x3 mm. As shown in drawing 3, it held vertically to the ground surface by fixing and attaching a periphery to the buck 3 fixed to the vertical wall 2 in this plate 18. And it is the plate 18 as shown in drawing 4 120 It decomposed into the

finite element of the individual and experimental mode analysis was conducted. From this analysis result to this plate It turned out that the 1st order to the 7th mode of vibration exists between 0 Hz - 40 Hz. When it assumes that the discharge of a sound and the quantity of a suction cancel drawing 5 mutually acoustically in the case of the symmetrical mode of vibration as the primary resonance frequency [5th] - the mode-of-vibration form in this case were shown and mentioned above, the mode of vibration which poses a problem here is the primary mode [5th].

[0016]Next, it is based on the mode-of-vibration form of the plate 18 of the distributed parameter system which was able to be found in experimental mode analysis under the above-mentioned consideration, and three mass points are specified as the position on the plate 18 shown in drawing 4, and 3 lumped mass models like drawing 4 are created. The spring constant of the spring between k_{ij} (i and j are the numbers of each mass point), and each mass point and a fixing face is defined for the spring constant of the spring which connects m_1, m_2, m_3, and each mass point for the mass of each mass point as k_i (i= 1, 2, 3) here. However, external force f_i (i= 1, 2, 3) which includes controlling force respectively shall act at each mass point. It is as follows when the equation of motion of these 3 lumped mass models is built.

[0017]

[Equation 1]

$$m_1X_1+(k_1+k_{12}+k_{13})x_1-k_{12}x_2-k_{13}x_3=f_1 \qquad (1)$$

$$m_2X_2+(k_{12}+k_2+k_{23})x_2-k_{12}x_1-k_{23}x_3=f_2 \qquad (2)$$

$$m_3X_3+(k_{13}+k_{23}+k_3)x_3-k_{23}x_2-k_{13}x_1=f_3 \qquad (3)$$

[0018]If this formula is indicated by a procession, [0019]

[Equation 2]

$$\begin{bmatrix} m_1 & 0 & 0 \\ 0 & m_2 & 0 \\ 0 & 0 & m_3 \end{bmatrix} \begin{Bmatrix} x_1 \\ x_2 \\ x_3 \end{Bmatrix} + \begin{bmatrix} k_1+k_{12}+k_{13} & -k_{12} & -k_{13} \\ -k_{12} & k_{12}+k_2+k_{23} & -k_{23} \\ -k_{13} & -k_{23} & k_{13}+k_{23}+k_3 \end{bmatrix} \begin{Bmatrix} x_1 \\ x_2 \\ x_3 \end{Bmatrix} = \begin{Bmatrix} f_1 \\ f_2 \\ f_3 \end{Bmatrix} \qquad (4)$$

[0020]It becomes. Then, the characteristic mode procession acquired by solving the eigenvalue problem of this formula is set as follows.

[0021]

[Equation 3]

$$\Phi = \begin{bmatrix} \phi_{11} & \phi_{12} & \phi_{13} \\ \phi_{21} & \phi_{22} & \phi_{23} \\ \phi_{31} & \phi_{32} & \phi_{33} \end{bmatrix} \qquad (5)$$

ただし ϕ_{ij}: (iは質点番号, jはモード次数)

[0022]On the other hand, it is the relation between the inverse matrix of the mass matrix M of a physical coordinate system, and a characteristic mode procession, [0023]

[Equation 4]

$$M^{-1}=\Phi\Phi^{T}=\begin{bmatrix}\phi_{11}^2+\phi_{22}^2+\phi_{33}^2 & A & B \\ A & \phi_{21}^2+\phi_{22}^2+\phi_{23}^2 & C \\ B & C & \phi_{31}^2+\phi_{32}^2+\phi_{33}^2\end{bmatrix} \quad (6)$$

ここに，

$A=\phi_{11}\phi_{21}+\phi_{12}\phi_{22}+\phi_{13}\phi_{23}$，$B=\phi_{11}\phi_{31}+\phi_{12}\phi_{32}+\phi_{13}\phi_{33}$

$C=\phi_{21}\phi_{31}+\phi_{22}\phi_{32}+\phi_{23}\phi_{33}$

モードの対称性により，

$\phi_{11}=\phi_{31}$，$\phi_{13}=\phi_{33}$，$\phi_{12}=-\phi_{32}$，$\phi_{22}=0$

[0024]From the character of a mass matrix without acceleration ganging, A, B, and C must be zero. Then, error-function epsilon$_1$ and epsilon$_2$ are defined as follows, and it considers bringing these close to zero.

[0025]

[Equation 5]

$A=C=\phi_{11}\phi_{21}+\phi_{13}\phi_{23}=\varepsilon_1$，$B=\phi_{11}^2-\phi_{12}^2+\phi_{13}^2=\varepsilon_2$

[0026]If the five variables phi 11 included in each formula, phi 21, phi 12, phi 13, and the sensitivity procession of phi 23 are defined like a formula (7) and a correction vector {deltaphi} is defined further, an error function can be brought close to zero by a formula (8).

[0027]

[Equation 6]

$$\begin{bmatrix}\dfrac{\partial\varepsilon_1}{\partial\phi} \\ \dfrac{\partial\varepsilon_2}{\partial\phi}\end{bmatrix}=\begin{bmatrix}\phi_{21} & \phi_{12} & 0 & \phi_{23} & \phi_{13} \\ 2\phi_{11} & 0 & -2\phi_{12} & 2\phi_{13} & 0\end{bmatrix} \quad (7)$$

$$\begin{bmatrix}\dfrac{\partial\varepsilon_1}{\partial\phi} \\ \dfrac{\partial\varepsilon_2}{\partial\phi}\end{bmatrix}\begin{Bmatrix}\delta\phi_{11} \\ \delta\phi_{21} \\ \delta\phi_{12} \\ \delta\phi_{13} \\ \delta\phi_{23}\end{Bmatrix}=-\begin{Bmatrix}\varepsilon_1 \\ \varepsilon_2\end{Bmatrix} \quad (8)$$

[0028]If the characteristic mode procession which diagonalizes a formula (6) is searched for and a mass matrix is calculated by a formula (8), it can be found as follows.

[0029]

[Equation 7]

$$\begin{bmatrix}m_1 & 0 & 0 \\ 0 & m_2 & 0 \\ 0 & 0 & m_3\end{bmatrix}=\begin{bmatrix}0.3075 & 0 & 0 \\ 0 & 0.5876 & 0 \\ 0 & 0 & 0.3075\end{bmatrix} \quad (9)$$

[0030]If a stiffness matrix is calculated, it can be found as follows.

[0031]

[Equation 8]

$$\begin{bmatrix} k_1+k_{12}+k_{13} & -k_{12} & -k_{13} \\ -k_{12} & k_{12}+k_2+k_{23} & -k_{23} \\ -k_{13} & -k_{23} & k_{13}+k_{23}+k_3 \end{bmatrix} = \begin{bmatrix} 0.69\times10^4 & -0.72\times10^4 & 0.30\times10^4 \\ -0.72\times10^4 & 1.22\times10^4 & -0.72\times10^4 \\ 0.30\times10^4 & -0.72\times10^4 & 0.69\times10^4 \end{bmatrix} \quad (10)$$

[0032]From these formulas, the physical constant of the lumped-parameter-system 3 flexibility model shown in drawing 4 can be found as follows.

[0033]

[Equation 9]

$$m_1=0.3075[kg],\ m_2=0.5876[kg],\ m_3=03075[kg]$$
$$k_1=0.28\times10^4[N/m],\ k_2=-0.21\times10^4[N/m]$$
$$k_3=0.28\times10^4[N/m],\ k_{12}=0.72\times10^4[N/m]$$
$$k_{23}=0.72\times10^4[N/m],\ k_{13}=-0.30\times10^4[N/m]$$

[0034]Comparison of the mode-of-vibration form obtained in actual experimental mode analysis and the mode-of-vibration type acquired by this modeling approach is shown in drawing 7. In the figure, thin solid lines are the mode form called for in experimental mode analysis, and the mode form from which the thick solid line was obtained with this modeling method, and it turns out that the mode is in agreement in three mass points.

[0035]The control system at the time of thinking as important that amplitude controls the mode of vibration which is the 1st greatest order, and attaching an actuator also in each mode, to the low dimension-ized model created as mentioned above, at a central mass point (mass m_2) is designed.

Since the point of this center is equivalent to the paragraph of the secondary mode of vibration [3rd / 4th], ****** is a point which is not about vibration of these modes. This point is equivalent to the point of the center of the actual plate 18.

[0036]The actuators 4 used in the active noise insulation method of this invention are improved goods of a loudspeaker.

As shown in drawing 9, it has the moving coil 6 twisted around the circumference of the movable core tube 5, and the ring like magnet 7 which surrounds this, and it has become the mechanism of driving the diaphragm 8 which made electromagnetic force acting on this and was attached to the movable core tube 3, by controlling the energization to the moving coil 6.

The actuator 4 is held in the middle position of the plate 18 by fixing the flange 7a of the ring like magnet 7 to the support member 9 of the couple which built the buck 2 of the plate 18 in parallel mutually, and was provided in it as shown in drawing 1 with the bolt 10, The connection with the plate 18 is made by connecting to the point of the center of the plate 18 the tip part of the connection binder 11 of the taper which protruded on the center section of the diaphragm 8 by methods, such as adhesion. In drawing 9, the supporter of the movable side element containing the diaphragm 8 to the fixed side element containing the ring like magnet 7 is modeled and shown by the spring (spring constant k_s) and the attenuation factor (damping coefficient C_s).

[0037]Then, the low dimension-ized physical model at the time of attaching this actuator 4 to the plate

18 is expressed like drawing 8. This physical model considers the support member 9 as a perfect rigid body.
It is equivalent to the model in the case of drawing 2 (a).

[0038]It is as follows, when the equation of motion at the time of attaching the actuator 4 to mass m_2 using this physical model is created and this is expressed with an equation of state.
[0039]
[Equation 10]

$$\dot{X} = AX + bu \qquad (17)$$

ここで，

$$X = [\dot{x}_1\ \dot{x}_2\ \dot{x}_3\ x_1\ x_2\ x_3] \qquad (18)$$

$$A = \begin{bmatrix} 0 & 0 & 0 & -\frac{k_1+k_{12}+k_{13}}{m_1} & \frac{k_{12}}{m_1} & \frac{k_{13}}{m_1} \\ 0 & \frac{C_3}{m_2} & 0 & \frac{k_{12}}{m_2} & -\frac{k_{12}+k_2+k_{23}+k_s}{m_2} & \frac{k_{23}}{m_2} \\ 0 & 0 & 0 & \frac{k_{13}}{m_3} & \frac{k_{23}}{m_3} & -\frac{k_{13}+k_{23}+k_3}{m_3} \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix} \qquad (19)$$

$$b = K_f \left[0\ \frac{1}{m_2}\ 0\ 0\ 0\ 0\ 0\right] \qquad (20)$$

[0040]Thus, if a control system is expressed with an equation of state, the optimal control theory which is modern control theory is applicable. In optimal control theory, the following state feedbacks determine a controlled variable.
[0041]
[Equation 11]

$$u = -KX \qquad (21)$$

$$K = [K_1\ K_2\ K_3\ K_4\ K_5\ K_6] \qquad (22)$$

ここで，Kは以下の評価関数Jを最小とするゲインである．ここでQおよびRは重み行列である．．

$$J = \int_0^{\infty} (XQX^t + uRu^t)dt \qquad (23)$$

[0042]The simulation of the vibration control of the plate 18 was performed using the above designed value. The result of the frequency response is shown in drawing 10. In the figure, (a) shows the frequency response in the point of the center of the plate 18, and (b) shows a response at the point of the sensor attached to one belly of the 5th mode of vibration of the plate 18. As shown in (a), when active control is added, the peak of vibration of the primary mode [5th] is decreasing, and an effective effect of intercepting noise can be expected. Since the fixing position of the actuator 4 is a center of the plate 18 in (b), to the secondary mode of vibration, become improper control, but. It turns out that the peak of the primary mode of vibration [5th] can be reduced without affecting the peak of the secondary mode of vibration from the result of this simulation.
[0043]Next, the time response corresponding to this frequency response is shown in drawing 11. The time response in the point of the center of the plate 18 is quickly converged by active vibration

control, as shown in the figure (a). As the time response in the point of the upper part of the plate 18 is shown in the figure (b), the secondary peak remains as well as a frequency response, but the primary mode [5th] is converged.

[0044]Next, as shown in drawing 3, the noncontact sensors 12c, 12u, and 12l. for detecting displacement of each point at the point Pc of the center of the plate 18 and the points Pu and Pl of two bellies (upper part and lower part) of the 5th mode of vibration are arranged, Each displacement data the case where the actuator 4 is operated, and in not operating was measured.

[0045]The composition of the controller 19 used in this experiment is shown in drawing 12. In this composition, the displacement signal from each noncontact sensors 12c, 12u, and 12l. is inputted into the personal computer 14 through A/D converter 13 by 1 kHz of sampling frequencies. The personal computer 14 computes a speed signal by differentiation of this displacement signal, and obtains each quantity of state. And a controlled variable is computed by carrying out the multiplication of the feedback gain which used and determined optimal control theory as the obtained quantity of state. After the controlled variable computed with the personal computer 14 is changed into an analog signal by D/A converter 15, it is amplified with the amplifier 16 and inputted into the actuator 4. With this input signal, the actuator 4 drives and vibration of the plate 18 is controlled.

[0046]Impulse excitation of the upper part of the plate 18 is carried out to drawing 13, and the frequency response obtained with the FFT-analysis machine is shown. In the figure, a dotted line is the response at the time of un-controlling, and a solid line is the response at the time of control. (a) is the response detected by the sensor 12c attached to the central part of the plate 18, and (b) shows the response at the point of the sensor 12u attached to the upper part of the plate 18. The peak of the primary frequency [5th] is observed for both sides at the time of un-controlling. When control is applied to this plate 18, it turns out that the primary peak value [5th] is falling greatly and vibration is controlled effectively. In drawing 14 (b), it is observed by having formed the actuator 4 in the point of the center of the plate 18 which is an improper control point of the secondary mode of vibration, without exciting vibration of the secondary mode. This is very well in agreement with the result of a simulation, and, thereby, the validity of 3 lumped mass models understands it. This experimental result shows that vibration can be controlled without carrying out spill OBAWO generating also about the 6th mode [7th] that is the simultaneous still higher order mode.

[0047]Therefore, by applying the composition of the above-mentioned control system to the wall 1 which divides the noise source room and sound receiving room of a actual building, vibration of the wall which participates in radiation of a sound can be prevented, and high insulation can be acquired, without using a weight wall, a honeycomb structure wall, etc. When applying this method to the actual wall 1, the personal computer 14 of the controller 19 shown in drawing 12 can be reset to the thing of the minimum necessary, such as a microcomputer chip and a memory device.

[0048]In the above-mentioned example, if the control system is designed in consideration of vibration of the support member 9 which supports the actuator 4, it is possible to be able to control vibration of a wall more effectively and to acquire insulation still higher than the above-mentioned example. The physical model for designing this control system is created, for example like drawing 14. In the model

shown in drawing 8, this physical model adds lumped mass m_c and spring constant k_c of the model element 9 of the support member 9, i.e., a support member, between the model element of the actuator 4, and a fixing face.

[0049]It is as follows, when the equation of motion is created using this physical model and this is expressed with an equation of state. However, since it is easy, attenuation factor C_s of the actuator 4 ignores.

[0050]

[Equation 12]

$$\begin{bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \\ \ddot{x}_3 \\ \ddot{x}_c \\ \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_c \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & -\frac{k_1+k_{12}+k_{13}}{m_1} & \frac{k_{12}}{m_1} & \frac{k_{13}}{m_1} & 0 \\ 0 & 0 & 0 & 0 & \frac{k_{12}}{m_2} & \frac{k_2+k_{12}+k_{23}+k_s}{m_2} & \frac{k_{23}}{m_3} & \frac{k_s}{m_2} \\ 0 & 0 & 0 & 0 & \frac{k_{13}}{m_3} & \frac{k_{23}}{m_3} & -\frac{k_3+k_{23}+k_{13}}{m_3} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{k_s}{m_c} & 0 & -\frac{k_c+k_s}{m_c} \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \\ \ddot{x}_3 \\ \ddot{x}_c \\ \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_c \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{k_c}{m_2} \\ 0 \\ -\frac{k_c}{m_c} \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} u \qquad (24)$$

[0051]By determining a controlled variable as this equation of state with the application of optimal control theory, a control system also including the support member 9 of the actuator 4 can be designed. The thing of the same composition as drawing 12 can be used for the control device in that case by changing a program, data, etc. which are stored in the computer 14.

[0052]The active noise insulation method of this invention is not limited to the above example, and, for example the mounting part of the actuator 4, As long as it is a part which does not excite the mode of vibration which can make damping force act on the mode of vibration which participates in radiation of a sound, and does not participate in radiation of a sound, except the center section of the plate 18 may be sufficient, and it may attach to two or more parts of the plate 18. When two or more actuators 4 are used, a control system will become more complicated than the above-mentioned example, but the vibration control of the plate 18 with higher insulation is possible.

[0053]It may replace with the above-mentioned noncontact sensors 12c, 12u, and 12l., and an acceleration sensor may be used. Since an acceleration sensor can be used for the plate 18, attaching it to it directly, erroneous detection of the vibration of the holding frame 3 etc. is not carried out as vibration of the plate 18, and it is suitable for the actual control system rather than the noncontact sensor.

[0054]The active noise insulation method of this invention can be applied to a griddle, a glass plate, and other various wallplates other than the plywood shown in the above-mentioned example, and can be applied effective also in the wall of a passenger car, a marine vessel, etc.

[0055]the example of being versatility, such as various studios and an engine room, can be considered besides the piano room shown in this example as an example of a noise room. If a wall is considered to be an outer wall of a hull, the feature of the ship recognized by the pattern of a sound is also arbitrarily changeable by the active noise insulation method of this invention.

[0056]

[Effect of the Invention]In short, according to the active noise insulation method of this invention, the outstanding effect like the following can be demonstrated above.

[0057](1) According to the invention according to claim 1, since vibration of a wall is controlled to specify the mode of vibration of the wall which participates in radiation of a sound, and to negate this, improvement in insulation can be aimed at, without using the large wall of the sound transmission loss of a weight wall, a honeycomb structure wall, etc.

[0058](2) According to the invention according to claim 2, the mode of vibration which participates in radiation of a sound can be easily specified by investigating the symmetry of a mode-of-vibration form.

[0059](3) According to the invention according to claim 3, vibration of a wall can be controlled to negate this only for vibration which participates in radiation of a sound, without exciting vibration of the mode of vibration which does not participate in radiation of a sound.

[Translation done.]

TECHNICAL FIELD

[Industrial Application]This invention relates to the active noise insulation method which improved insulation by controlling vibration of a wall in consideration of the oscillation characteristic of the wall which divides a noise source room and a sound receiving room.

[Translation done.]

PRIOR ART

[Description of the Prior Art]How to negate the sound emitted from the noise source as a measure against noise in the air, and the method of intercepting the propagation path of a sound on the way can be considered. The noise control art what is called by an active canceler which detects the sound from a noise source with a microphone, generates the signal of it, and an opposite phase and the same amplitude by a loudspeaker, and cancels the sound near a noise detecting point about the former (offset) appears, It applies to noise reductions, such as the shrine interior of a room of a duct, a refrigerator, and a passenger car, and the result is got. About the latter, the passive method of covering noise is still adopted by dividing with the large wall of sound transmission loss between the sound receiving rooms which wish the noise source room which builds in a noise source, and a noise reduction.

[Translation done.]

EFFECT OF THE INVENTION

[Effect of the Invention]In short, according to the active noise insulation method of this invention, the outstanding effect like the following can be demonstrated above.
[0057](1) According to the invention according to claim 1, since vibration of a wall is controlled to specify the mode of vibration of the wall which participates in radiation of a sound, and to negate this, improvement in insulation can be aimed at, without using the large wall of the sound transmission loss of a weight wall, a honeycomb structure wall, etc.
[0058](2) According to the invention according to claim 2, the mode of vibration which participates in radiation of a sound can be easily specified by investigating the symmetry of a mode-of-vibration form.
[0059](3) According to the invention according to claim 3, vibration of a wall can be controlled to negate this only for vibration which participates in radiation of a sound, without exciting vibration of the mode of vibration which does not participate in radiation of a sound.

[Translation done.]

TECHNICAL PROBLEM

[Problem(s) to be Solved by the Invention]However. [whether material with large specific gravity of lead, iron, etc. is used for a wall in order to acquire high insulation by the conventional noise insulation method, and] Or application is difficult under the condition where needs to use thick sound-absorbing materials, such as honeycomb structure, etc., and a weight saving is required like a present-day building and which has restriction also in capacity.
[0004]This invention is originated under such a situation, and the purpose is to provide the active noise insulation method that high insulation can be acquired, without using a weight wall, a honeycomb structure wall, etc.

[Translation done.]

MEANS

[Means for Solving the Problem]To achieve the above objects, in an active noise insulation method of this invention, The mode of vibration which analyzes the mode of vibration of a wall which divides a noise source room and a sound receiving room, and participates in radiation of a sound is specified, Arrange a sensor for detecting the acceleration of vibration thru/or speed on each point of a wall corresponding to each mass point of a low dimension-ized model obtained by creating a low dimension-ized model of a wall in the mode of vibration, and an actuator for making damping force act on a wall is attached to at least one place of a wall, An actuator is driven that vibration of a wall should be controlled based on a detecting signal from each sensor.
[0006]In a noise insulation method of this invention, it is desirable to specify the mode in which the mode-of-vibration form is a non-object acoustically, as the mode of vibration which participates in radiation of the above-mentioned sound.
[0007]In a noise insulation method of this invention, it is desirable to attach the above-mentioned actuator to a part corresponding to a mass point of the above-mentioned low dimension-ized model of the above-mentioned wall.

[Translation done.]

OPERATION

[Function]The active noise insulation method of this invention tends to control vibration of a wall to negate this only for vibration which participates in radiation of a sound paying attention to the point that the leakage of the sound occurs, when the wall which divides a noise source room and a sound receiving room resonates with noise and vibrates. since modern control theory effective in vibration control is unutilizable if the model of a controlled object is not specified, but a wall has the characteristic of the distribution constant of infinite flexibility -- model creation of limited flexibility -- it is necessary to carry out And if flexibility is large, a controller will be enlarged, and since many number of sensors is necessities, it is desirable to low-dimension-ize a model to necessary minimum. Therefore, in the method of this invention, the mode of vibration which participates in radiation of a sound out of the mode of vibration which conducts mode-of-vibration analysis of a wall first, and exist in the predetermined frequency area which is going to insulate is specified, and the low dimension-ized model of the wall in the mode of vibration is created. Thus, it becomes possible to design a control system with the application of modern control theory by creating the low dimension-ized model of a controlled object. By and the thing for which the sensor for each point of the wall corresponding to each mass point of the obtained low dimension-ized model, i.e., near the peak magnitude point of the mode of vibration which were pinpointed, detecting the acceleration of vibration thru/or displacement is arranged. The vibrational state of a controlled object, i.e., a wall, can be observed, and vibration of a wall can be effectively controlled by driving an actuator based on the detecting signal from each sensor.
[0009]Drawing 5 is a monotonous example of mode-of-vibration analysis which constitutes a wall, and the 1-5th resonance frequency and a mode-of-vibration form are shown. When its attention is paid to the symmetry of a mode-of-vibration form, acoustically the 2-4th mode-of-vibration forms Symmetry, When it assumes that the primary mode-of-vibration form [5th] is acoustically unsymmetrical, and the discharge of a sound and the quantity of a suction cancel it mutually acoustically in the case of the symmetrical mode, the mode of vibration which poses a problem which participates in radiation of a sound is the primary mode [5th] that is the unsymmetrical mode acoustically. Thus, by investigating the symmetry of a mode-of-vibration form, the mode of vibration which participates in

radiation of a sound can be specified easily.

[0010]Thus, the peak magnitude point of the specified mode of vibration is equivalent to the paragraph of other modes of vibration which do not participate in radiation of a sound. Therefore, vibration of a wall can be controlled to negate this only for vibration which participates in radiation of a sound, without exciting vibration of the mode of vibration which does not participate in radiation of a sound, if the actuator is attached to this point. That is, if an actuator is attached to the paragraph of the mode of vibration and improper control and a sensor will be attached, the active noise insulation method of this invention will arrange a sensor or an actuator in the paragraph in the mode in which he would like to ignore, using becoming improper observation, and will control vibration of a wall. According to this method, the control system which can prevent spillover structurally can be built.

[Translation done.]

EXAMPLE

[Example]Next, the example of the active noise insulation method of this invention is described.
[0012]An example when drawing 1 applies the active noise insulation method of this invention to the wall 1 which divides the noise source room (piano room) A and the sound receiving room (study for children) B is shown. Since it is transmitted to the sound receiving room B via the wall 1, if the noise of the noise source room A drives the actuator 4 based on the signal from the vibration sensors 12c, 12u, and 12l. attached to the wall 1 and vibration of the wall 1 is controlled effectively, the noise level of the sound receiving room B will reduce it substantially.
[0013]Two kinds of gestalten of the equipment configuration taken in order to control vibration of a wall by the technique of this invention actively are shown in drawing 2. The figure (a) is a method which makes a fixing face support the actuator 4, attaches to the wall 1, controls the actuator 4 by the controlled variable made by the controller 19 based on the sensors [12c, 12u, and 12l.] detecting signal, and makes damping force act on the wall 1.
The figure (b) is a method which attaches the actuator 4 to the wall 1 via an elastic body (here, a model is made by the retaining spring 20), and makes the damping force of the actuator 4 act on the wall 1 by making into reaction force the inertia force of the auxiliary mass md provided in the actuator 4 instead of the fixing face.
In the figure (a), when a fixing face is not acquired, the actuator 4 is separately supported by a support member. In that case, it is desirable to design the controller 19 in consideration of the characteristic of a support structure.
[0014]Next, in order to show the validity of the active noise insulation method of this invention, a simulation and an experiment show the case which constitutes the wall of a building where this method is applied monotonously.
[0015]The plate used for the experiment is plywood of 1200x1000x3 mm. As shown in drawing 3, it held vertically to the ground surface by fixing and attaching a periphery to the buck 3 fixed to the vertical wall 2 in this plate 18. And it is the plate 18 as shown in drawing 4 120 It decomposed into the finite element of the individual and experimental mode analysis was conducted. From this analysis result to this plate It turned out that the 1st order to the 7th mode of vibration exists between 0 Hz - 40

Hz. When it assumes that the discharge of a sound and the quantity of a suction cancel drawing 5 mutually acoustically in the case of the symmetrical mode of vibration as the primary resonance frequency [5th] - the mode-of-vibration form in this case were shown and mentioned above, the mode of vibration which poses a problem here is the primary mode [5th].

[0016]Next, it is based on the mode-of-vibration form of the plate 18 of the distributed parameter system which was able to be found in experimental mode analysis under the above-mentioned consideration, and three mass points are specified as the position on the plate 18 shown in drawing 4, and 3 lumped mass models like drawing 4 are created. The spring constant of the spring between k_{ij} (i and j are the numbers of each mass point), and each mass point and a fixing face is defined for the spring constant of the spring which connects m_1, m_2, m_3, and each mass point for the mass of each mass point as k_i (i= 1, 2, 3) here. However, external force f_i (i= 1, 2, 3) which includes controlling force respectively shall act at each mass point. It is as follows when the equation of motion of these 3 lumped mass models is built.

[0017]

[Equation 1]

$$m_1X_1+(k_1+k_{12}+k_{13})x_1-k_{12}x_2-k_{13}x_3=f_1 \qquad (1)$$

$$m_2X_2+(k_{12}+k_2+k_{23})x_2-k_{12}x_1-k_{23}x_3=f_2 \qquad (2)$$

$$m_3X_3+(k_{13}+k_{23}+k_3)x_3-k_{23}x_2-k_{13}x_1=f_3 \qquad (3)$$

[0018]If this formula is indicated by a procession, [0019]

[Equation 2]

$$\begin{bmatrix} m_1 & 0 & 0 \\ 0 & m_2 & 0 \\ 0 & 0 & m_3 \end{bmatrix} \begin{Bmatrix} x_1 \\ x_2 \\ x_3 \end{Bmatrix} + \begin{bmatrix} k_1+k_{12}+k_{13} & -k_{12} & -k_{13} \\ -k_{12} & k_{12}+k_2+k_{23} & -k_{23} \\ -k_{13} & -k_{23} & k_{13}+k_{23}+k_3 \end{bmatrix} \begin{Bmatrix} x_1 \\ x_2 \\ x_3 \end{Bmatrix} = \begin{Bmatrix} f_1 \\ f_2 \\ f_3 \end{Bmatrix} \qquad (4)$$

[0020]It becomes. Then, the characteristic mode procession acquired by solving the eigenvalue problem of this formula is set as follows.

[0021]

[Equation 3]

$$\Phi = \begin{bmatrix} \phi_{11} & \phi_{12} & \phi_{13} \\ \phi_{21} & \phi_{22} & \phi_{23} \\ \phi_{31} & \phi_{32} & \phi_{33} \end{bmatrix} \qquad (5)$$

ただし ϕ_{ij}:（iは質点番号，jはモード次数）

[0022]On the other hand, it is the relation between the inverse matrix of the mass matrix M of a physical coordinate system, and a characteristic mode procession, [0023]

[Equation 4]

$$M^{-1}=\Phi\Phi^T=\begin{bmatrix}\phi_{11}^2+\phi_{22}^2+\phi_{33}^2 & A & B\\ A & \phi_{21}^2+\phi_{22}^2+\phi_{23}^2 & C\\ B & C & \phi_{31}^2+\phi_{32}^2+\phi_{33}^2\end{bmatrix} \qquad (6)$$

ここに,

$A=\phi_{11}\phi_{21}+\phi_{12}\phi_{22}+\phi_{13}\phi_{23}$, $B=\phi_{11}\phi_{31}+\phi_{12}\phi_{32}+\phi_{13}\phi_{33}$

$C=\phi_{21}\phi_{31}+\phi_{22}\phi_{32}+\phi_{23}\phi_{33}$

モードの対称性により,

$\phi_{11}=\phi_{31}$, $\phi_{13}=\phi_{33}$, $\phi_{12}=-\phi_{32}$, $\phi_{22}=0$

[0024]From the character of a mass matrix without acceleration ganging, A, B, and C must be zero. Then, error-function epsilon$_1$ and epsilon$_2$ are defined as follows, and it considers bringing these close to zero.

[0025]

[Equation 5]

$A=C=\phi_{11}\phi_{21}+\phi_{13}\phi_{23}=\varepsilon_1$, $B=\phi_{11}^2-\phi_{12}^2+\phi_{13}^2=\varepsilon_2$

[0026]If the five variables phi 11 included in each formula, phi 21, phi 12, phi 13, and the sensitivity procession of phi 23 are defined like a formula (7) and a correction vector {deltaphi} is defined further, an error function can be brought close to zero by a formula (8).

[0027]

[Equation 6]

$$\begin{bmatrix}\dfrac{\partial\varepsilon_1}{\partial\phi}\\ \dfrac{\partial\varepsilon_2}{\partial\phi}\end{bmatrix}=\begin{bmatrix}\phi_{21} & \phi_{12} & 0 & \phi_{23} & \phi_{13}\\ 2\phi_{11} & 0 & -2\phi_{12} & 2\phi_{13} & 0\end{bmatrix} \qquad (7)$$

$$\begin{bmatrix}\dfrac{\partial\varepsilon_1}{\partial\phi}\\ \dfrac{\partial\varepsilon_2}{\partial\phi}\end{bmatrix}\begin{Bmatrix}\delta\phi_{11}\\ \delta\phi_{21}\\ \delta\phi_{12}\\ \delta\phi_{13}\\ \delta\phi_{23}\end{Bmatrix}=-\begin{Bmatrix}\varepsilon_1\\ \varepsilon_2\end{Bmatrix} \qquad (8)$$

[0028]If the characteristic mode procession which diagonalizes a formula (6) is searched for and a mass matrix is calculated by a formula (8), it can be found as follows.

[0029]

[Equation 7]

$$\begin{bmatrix}m_1 & 0 & 0\\ 0 & m_2 & 0\\ 0 & 0 & m_3\end{bmatrix}=\begin{bmatrix}0.3075 & 0 & 0\\ 0 & 0.5876 & 0\\ 0 & 0 & 0.3075\end{bmatrix} \qquad (9)$$

[0030]If a stiffness matrix is calculated, it can be found as follows.

[0031]

[Equation 8]

$$\begin{bmatrix} k_1+k_{12}+k_{13} & -k_{12} & -k_{13} \\ -k_{12} & k_{12}+k_2+k_{23} & -k_{23} \\ -k_{13} & -k_{23} & k_{13}+k_{23}+k_3 \end{bmatrix} = \begin{bmatrix} 0.69\times10^4 & -0.72\times10^4 & 0.30\times10^4 \\ -0.72\times10^4 & 1.22\times10^4 & -0.72\times10^4 \\ 0.30\times10^4 & -0.72\times10^4 & 0.69\times10^4 \end{bmatrix} \qquad (10)$$

[0032]From these formulas, the physical constant of the lumped-parameter-system 3 flexibility model shown in drawing 4 can be found as follows.

[0033]

[Equation 9]

$$m_1=0.3075[kg],\ m_2=0.5876[kg],\ m_3=03075[kg]$$
$$k_1=0.28\times10^4[N/m],\ k_2=-0.21\times10^4[N/m]$$
$$k_3=0.28\times10^4[N/m],\ k_{12}=0.72\times10^5[N/m]$$
$$k_{23}=0.72\times10^4[N/m],\ k_{13}=-0.30\times10^4[N/m]$$

[0034]Comparison of the mode-of-vibration form obtained in actual experimental mode analysis and the mode-of-vibration type acquired by this modeling approach is shown in drawing 7. In the figure, thin solid lines are the mode form called for in experimental mode analysis, and the mode form from which the thick solid line was obtained with this modeling method, and it turns out that the mode is in agreement in three mass points.

[0035]The control system at the time of thinking as important that amplitude controls the mode of vibration which is the 1st greatest order, and attaching an actuator also in each mode, to the low dimension-ized model created as mentioned above, at a central mass point (mass m_2) is designed.

Since the point of this center is equivalent to the paragraph of the secondary mode of vibration [3rd / 4th], ****** is a point which is not about vibration of these modes. This point is equivalent to the point of the center of the actual plate 18.

[0036]The actuators 4 used in the active noise insulation method of this invention are improved goods of a loudspeaker.

As shown in drawing 9, it has the moving coil 6 twisted around the circumference of the movable core tube 5, and the ring like magnet 7 which surrounds this, and it has become the mechanism of driving the diaphragm 8 which made electromagnetic force acting on this and was attached to the movable core tube 3, by controlling the energization to the moving coil 6.

The actuator 4 is held in the middle position of the plate 18 by fixing the flange 7a of the ring like magnet 7 to the support member 9 of the couple which built the buck 2 of the plate 18 in parallel mutually, and was provided in it as shown in drawing 1 with the bolt 10, The connection with the plate 18 is made by connecting to the point of the center of the plate 18 the tip part of the connection binder 11 of the taper which protruded on the center section of the diaphragm 8 by methods, such as adhesion. In drawing 9, the supporter of the movable side element containing the diaphragm 8 to the fixed side element containing the ring like magnet 7 is modeled and shown by the spring (spring constant k_s) and the attenuation factor (damping coefficient C_s).

[0037]Then, the low dimension-ized physical model at the time of attaching this actuator 4 to the plate

18 is expressed like drawing 8. This physical model considers the support member 9 as a perfect rigid body.
It is equivalent to the model in the case of drawing 2 (a).

[0038]It is as follows, when the equation of motion at the time of attaching the actuator 4 to mass m_2 using this physical model is created and this is expressed with an equation of state.
[0039]
[Equation 10]

$$\dot{X} = AX + bu \tag{17}$$

ここで，

$$X = [\dot{x}_1\ \dot{x}_2\ \dot{x}_3\ x_1\ x_2\ x_3] \tag{18}$$

$$A = \begin{bmatrix} 0 & 0 & 0 & -\frac{k_1+k_{12}+k_{13}}{m_1} & \frac{k_{12}}{m_1} & \frac{k_{13}}{m_1} \\ 0 & \frac{C_s}{m_2} & 0 & \frac{k_{12}}{m_2} & -\frac{k_{12}+k_2+k_{23}+k_s}{m_2} & \frac{k_{23}}{m_2} \\ 0 & 0 & 0 & \frac{k_{13}}{m_3} & \frac{k_{23}}{m_3} & -\frac{k_{13}+k_{23}+k_3}{m_3} \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix} \tag{19}$$

$$b = K_f \left[0\ \frac{1}{m_2}\ 0\ 0\ 0\ 0\ 0\right] \tag{20}$$

[0040]Thus, if a control system is expressed with an equation of state, the optimal control theory which is modern control theory is applicable. In optimal control theory, the following state feedbacks determine a controlled variable.
[0041]
[Equation 11]

$$u = -KX \tag{21}$$

$$K = [K_1\ K_2\ K_3\ K_4\ K_5\ K_6] \tag{22}$$

ここで，Kは以下の評価関数Jを最小とするゲインである．ここでQおよびRは重み行列である．．

$$J = \int_0^{\infty} (XQX^t + uRu^t)dt \tag{23}$$

[0042]The simulation of the vibration control of the plate 18 was performed using the above designed value. The result of the frequency response is shown in drawing 10. In the figure, (a) shows the frequency response in the point of the center of the plate 18, and (b) shows a response at the point of the sensor attached to one belly of the 5th mode of vibration of the plate 18. As shown in (a), when active control is added, the peak of vibration of the primary mode [5th] is decreasing, and an effective effect of intercepting noise can be expected. Since the fixing position of the actuator 4 is a center of the plate 18 in (b), to the secondary mode of vibration, become improper control, but. It turns out that the peak of the primary mode of vibration [5th] can be reduced without affecting the peak of the secondary mode of vibration from the result of this simulation.
[0043]Next, the time response corresponding to this frequency response is shown in drawing 11. The time response in the point of the center of the plate 18 is quickly converged by active vibration

control, as shown in the figure (a). As the time response in the point of the upper part of the plate 18 is shown in the figure (b), the secondary peak remains as well as a frequency response, but the primary mode [5th] is converged.

[0044]Next, as shown in drawing 3, the noncontact sensors 12c, 12u, and 12l. for detecting displacement of each point at the point Pc of the center of the plate 18 and the points Pu and Pl of two bellies (upper part and lower part) of the 5th mode of vibration are arranged, Each displacement data the case where the actuator 4 is operated, and in not operating was measured.

[0045]The composition of the controller 19 used in this experiment is shown in drawing 12. In this composition, the displacement signal from each noncontact sensors 12c, 12u, and 12l. is inputted into the personal computer 14 through A/D converter 13 by 1 kHz of sampling frequencies. The personal computer 14 computes a speed signal by differentiation of this displacement signal, and obtains each quantity of state. And a controlled variable is computed by carrying out the multiplication of the feedback gain which used and determined optimal control theory as the obtained quantity of state. After the controlled variable computed with the personal computer 14 is changed into an analog signal by D/A converter 15, it is amplified with the amplifier 16 and inputted into the actuator 4. With this input signal, the actuator 4 drives and vibration of the plate 18 is controlled.

[0046]Impulse excitation of the upper part of the plate 18 is carried out to drawing 13, and the frequency response obtained with the FFT-analysis machine is shown. In the figure, a dotted line is the response at the time of un-controlling, and a solid line is the response at the time of control. (a) is the response detected by the sensor 12c attached to the central part of the plate 18, and (b) shows the response at the point of the sensor 12u attached to the upper part of the plate 18. The peak of the primary frequency [5th] is observed for both sides at the time of un-controlling. When control is applied to this plate 18, it turns out that the primary peak value [5th] is falling greatly and vibration is controlled effectively. In drawing 14 (b), it is observed by having formed the actuator 4 in the point of the center of the plate 18 which is an improper control point of the secondary mode of vibration, without exciting vibration of the secondary mode. This is very well in agreement with the result of a simulation, and, thereby, the validity of 3 lumped mass models understands it. This experimental result shows that vibration can be controlled without carrying out spill OBAWO generating also about the 6th mode [7th] that is the simultaneous still higher order mode.

[0047]Therefore, by applying the composition of the above-mentioned control system to the wall 1 which divides the noise source room and sound receiving room of a actual building, vibration of the wall which participates in radiation of a sound can be prevented, and high insulation can be acquired, without using a weight wall, a honeycomb structure wall, etc. When applying this method to the actual wall 1, the personal computer 14 of the controller 19 shown in drawing 12 can be reset to the thing of the minimum necessary, such as a microcomputer chip and a memory device.

[0048]In the above-mentioned example, if the control system is designed in consideration of vibration of the support member 9 which supports the actuator 4, it is possible to be able to control vibration of a wall more effectively and to acquire insulation still higher than the above-mentioned example. The physical model for designing this control system is created, for example like drawing 14. In the model

shown in drawing 8, this physical model adds lumped mass m_c and spring constant k_c of the model element 9 of the support member 9, i.e., a support member, between the model element of the actuator 4, and a fixing face.

[0049]It is as follows, when the equation of motion is created using this physical model and this is expressed with an equation of state. However, since it is easy, attenuation factor C_s of the actuator 4 ignores.

[0050]

[Equation 12]

$$\begin{bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \\ \ddot{x}_3 \\ \ddot{x}_c \\ \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_c \end{bmatrix} = \begin{bmatrix} 0\,0\,0\,0 & -\frac{k_1+k_{12}+k_{13}}{m_1} & \frac{k_{12}}{m_1} & \frac{k_{13}}{m_1} & 0 \\ 0\,0\,0\,0 & \frac{k_{12}}{m_2} & \frac{k_2+k_{12}+k_{23}+k_s}{m_2} & \frac{k_{23}}{m_2} & \frac{k_s}{m_2} \\ 0\,0\,0\,0 & \frac{k_{13}}{m_3} & \frac{k_{23}}{m_3} & -\frac{k_3+k_{23}+k_{13}}{m_3} & 0 \\ 0\,0\,0\,0 & 0 & \frac{k_s}{m_c} & 0 & -\frac{k_c+k_s}{m_c} \\ 1\,0\,0\,0 & 0 & 0 & 0 & 0 \\ 0\,1\,0\,0 & 0 & 0 & 0 & 0 \\ 0\,0\,1\,0 & 0 & 0 & 0 & 0 \\ 0\,0\,0\,1 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \\ \ddot{x}_3 \\ \ddot{x}_c \\ \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_c \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{k_c}{m_2} \\ 0 \\ -\frac{k_c}{m_c} \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} u \qquad (24)$$

[0051]By determining a controlled variable as this equation of state with the application of optimal control theory, a control system also including the support member 9 of the actuator 4 can be designed. The thing of the same composition as drawing 12 can be used for the control device in that case by changing a program, data, etc. which are stored in the computer 14.

[0052]The active noise insulation method of this invention is not limited to the above example, and, for example the mounting part of the actuator 4, As long as it is a part which does not excite the mode of vibration which can make damping force act on the mode of vibration which participates in radiation of a sound, and does not participate in radiation of a sound, except the center section of the plate 18 may be sufficient, and it may attach to two or more parts of the plate 18. When two or more actuators 4 are used, a control system will become more complicated than the above-mentioned example, but the vibration control of the plate 18 with higher insulation is possible.

[0053]It may replace with the above-mentioned noncontact sensors 12c, 12u, and 12l., and an acceleration sensor may be used. Since an acceleration sensor can be used for the plate 18, attaching it to it directly, erroneous detection of the vibration of the holding frame 3 etc. is not carried out as vibration of the plate 18, and it is suitable for the actual control system rather than the noncontact sensor.

[0054]The active noise insulation method of this invention can be applied to a griddle, a glass plate, and other various wallplates other than the plywood shown in the above-mentioned example, and can be applied effective also in the wall of a passenger car, a marine vessel, etc.

[0055]the example of being versatility, such as various studios and an engine room, can be considered besides the piano room shown in this example as an example of a noise room. If a wall is considered to be an outer wall of a hull, the feature of the ship recognized by the pattern of a sound is also arbitrarily changeable by the active noise insulation method of this invention.

[Translation done.]

DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]
[Drawing 1]It is a key map showing one example of the active noise insulation method of this invention.
[Drawing 2]It is a schematic diagram showing the equipment configuration for carrying out active noise insulation of this invention.
[Drawing 3]It is a figure showing an example of an experimental device for the validity of the active noise insulation method of this invention to be shown, and (a) is a front view and (b) is an A-A'sectional view of (a).
[Drawing 4]It is a key map showing the mass of a monotonous structure which constitutes a wall, and its physical model.
[Drawing 5]It is a figure showing the monotonous mode of vibration acquired in experimental mode analysis.
[Drawing 6]It is a figure showing a monotonous physical model (low dimension-ized model).
[Drawing 7]It is a figure showing the monotonous mode-of-vibration form obtained by an experiment and calculation, and its monotonous low dimension-ized model.
[Drawing 8]It is a figure showing the physical model at the time of attaching an actuator.
[Drawing 9]It is a sectional view showing the structure of an actuator.
[Drawing 10]It is a figure showing the result of the frequency response by a simulation.
[Drawing 11]It is a figure showing the time response corresponding to the frequency response of drawing 8.
[Drawing 12]It is a lineblock diagram of the controller used for the experiment.
[Drawing 13]It is a figure showing the result of the frequency response by a simulation.
[Drawing 14]It is a figure showing other examples of the physical model at the time of attaching an actuator.
[Description of Notations]
1 Wall
4 Actuator

12c Sensor

12u Sensor

12 l. Sensor

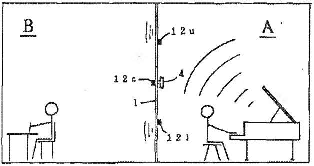
A Noise source room

B Sound receiving room

[Translation done.]

DRAWINGS

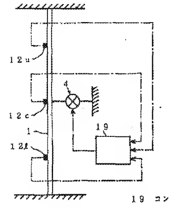
[Drawing 1]



1 壁
4 アクチュエータ
12c センサ
12u センサ
12l センサ

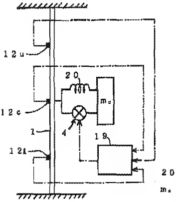
[Drawing 2]

(a)



19 コントローラ

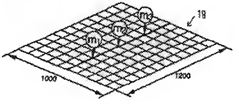
(b)



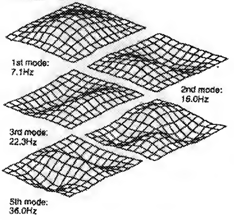
20 支持ばね

m_d 補助質量

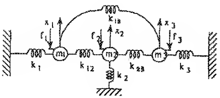
[Drawing 4]



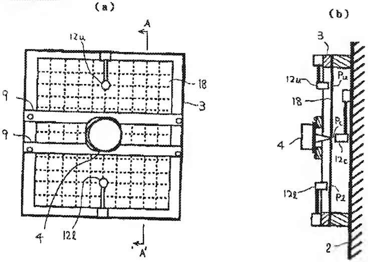
[Drawing 5]



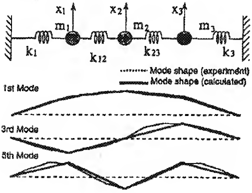
[Drawing 6]



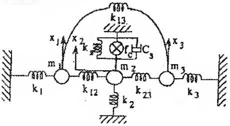
[Drawing 3]



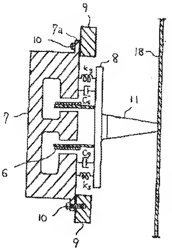
[Drawing 7]



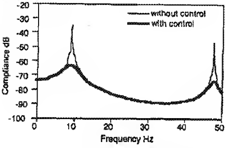
[Drawing 8]



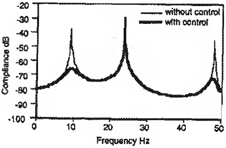
[Drawing 9]



[Drawing 10]

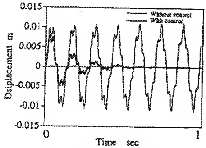


(a) center point

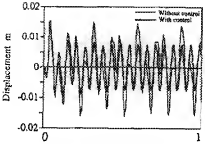


(b) upper point

[Drawing 11]

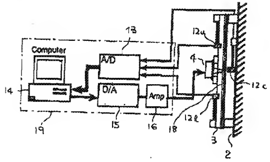


(a) center point

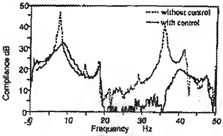


(b) upper point

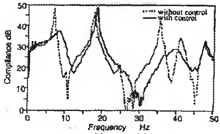
[Drawing 12]



[Drawing 13]

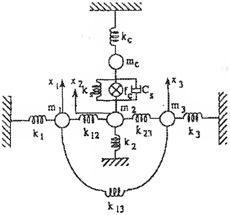


(a) center point



(b) upper point

[Drawing 14]



[Translation done.]